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|---|---|---|
| 1. REPORT NUMBER | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle)<br>SOUND PROPAGATION FROM A COASTAL SOURCE TO A DEEP OCEAN RECEIVER | | 5. TYPE OF REPORT & PERIOD COVERED<br>FINAL |
| | | 6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s)<br>WILLIAM M. CAREY | | 8. CONTRACT OR GRANT NUMBER(s) |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>NAVAL OCEAN RESEARCH AND DEVELOPMENT ACTIVITY<br>800 NORTH QUINCY STREET<br>ARLINGTON, VIRGINIA 22217 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>PE 63785N-0120-300 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS<br>NAVAL OCEAN RESEARCH AND DEVELOPMENT ACTIVITY<br>AEAS PROGRAM OFFICE<br>NSTL, MISSISSIPPI 39529 | | 12. REPORT DATE<br>13 MAY 1983 |
| | | 13. NUMBER OF PAGES<br>26 |
| 14. MONITORING AGENCY NAME & ADDRESS(If different from Controlling Office) | | 15. SECURITY CLASS. (of this report)<br>UNCLASSIFIED |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

APPROVED FOR PUBLIC RELEASE DISTRIBUTION UNLIMITED

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

| | |
|---|---|
| SOUND PROPAGATION | GULF STREAM |
| SABLE ISLAND BANK | DEEP OCEAN NOISE |
| SARGASSO SEA | |

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An experiment has been performed to investigate the coupling of surface ship noise to the deep ocean sound channel. These calibrated measurements of sound propagation from the 18 m, 135 Hz source were obtained at a deep ocean receiver while the source tow proceeded from deep water up the Sable Island Bank at ranges between 730 and 910 km. The sound propagation path was from the edge of the Sargasso Sea, through the Gulf Stream and into the cold slope waters over the bank. The mean value of the transmission loss was 110 dB with a slope en-hancement estimated to be 4 dB resulting from the combined effects of trapping

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20. cont

in the strong shallow sound channel and reflections from the slope. Comparisons with PE calculated results were good and indicated a strong coupling to the deep ocean sound channel. The acoustic field, sampled by sixteen transverse hydrophones over six consecutive (12.5 sec, .08 Hz) samples, yielded a standard deviation of 1.7 dB ($6 \leq s/n \leq 20$ dB), consistent with theoretical expectations of a well behaved multipath field. Coherent summation of slope reflected and deep refracted hydrophone signals yielded estimated mean values of the spatial coherence of 0.89 and a spatial coherence length of 460 meters, when multipath effects were not dominant; however, these estimates were found to range as low as 0.63 and 150 meters. These results will facilitate interpretation of the spatial coherence of the ship-induced "slope-enhanced" contribution to deep ocean noise.

NORDA  SP 41:84:113

# SOUND PROPAGATION FROM A COASTAL SOURCE TO A DEEP OCEAN RECEIVER

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*NSTL, Mississippi 39529*

# PREFACE

This paper was presented at the 105 Spring Meeting of the American Acoustical Society of America and is issued in response to several requests for copies of the presentation. The work presented in this paper spanned several years of effort under the sponsorship of Dr. Robert Gardner, NORDA Code 260. In the course of this investigation, my affiliation spanned a commercial enterprise, the Naval Research Laboratory and NORDA. Requests for additional information should be addressed to the NORDA Liaison Office, 800 North Quincy Street, Arlington, Virginia 22217.

# ABSTRACT

Sound propagation from a coastal source to a deep ocean receiver.
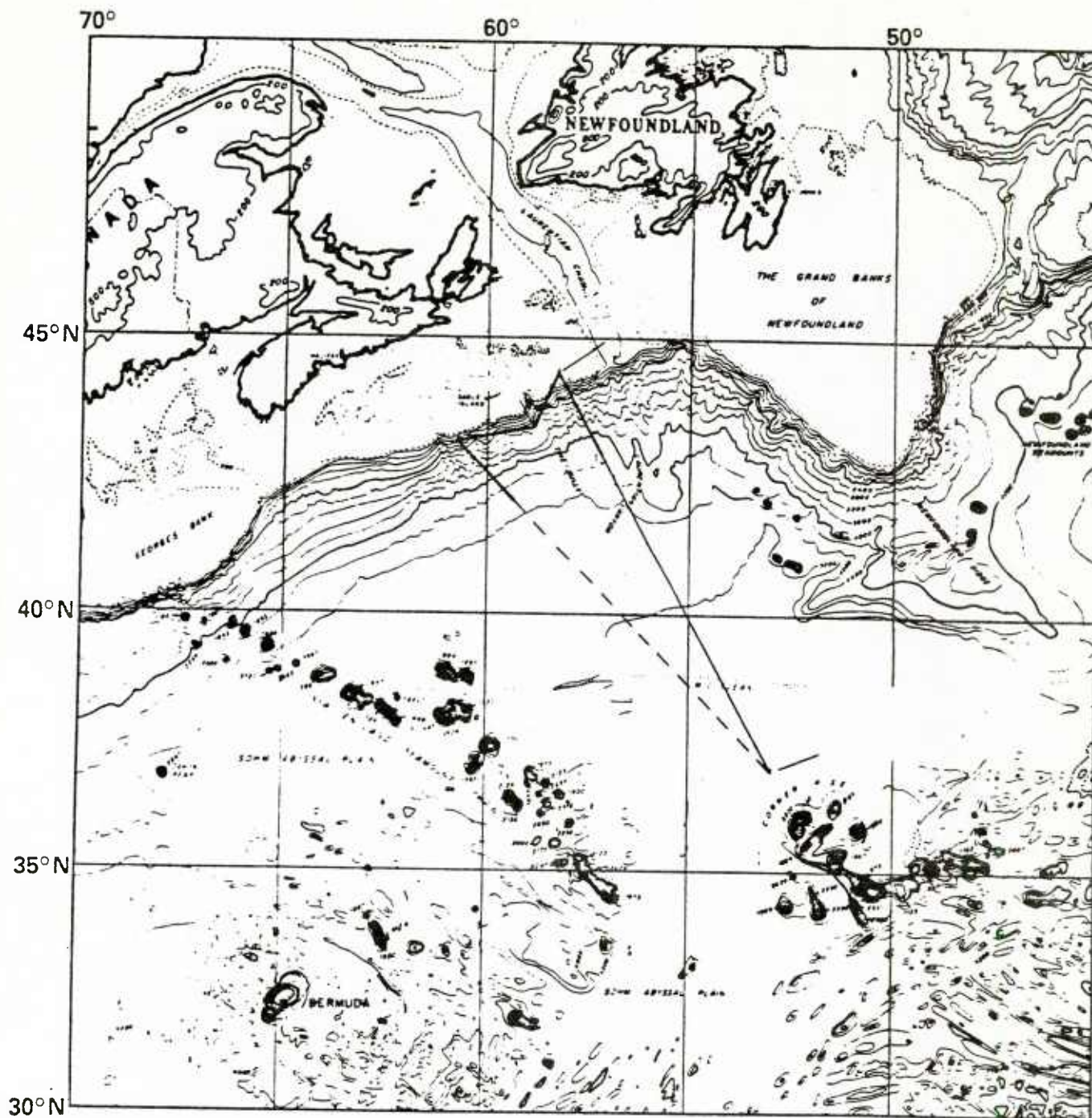William M. Carey (Code 5160, Naval Research Laboratory, Washington, DC 20375)

An experiment has been performed to investigate the coupling of surface ship
noise to the deep ocean sound channel. These calibrated measurements of sound
propagation from the 18 m, 135 Hz source were obtained at a deep ocean receiver
while the source tow proceeded from deep water up the Sable Island Bank at
ranges between 730 and 910 km. The sound propagation path was from the edge of
the Sargasso Sea, through the Gulf Stream and into the cold slope waters over
the bank. The mean value of the transmission loss was 110 dB with a slope en-
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in the strong shallow sound channel and reflections from the slope. Comparisons
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ocean sound channel. The acoustic field, sampled by sixteen transverse hydro-
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coherence of 0.89 and a spatial coherence length of 460 meters, when multipath
effects were not dominant; however, these estimates were found to range as low
as 0.63 and 150 meters. These results will facilitate interpretation of the
spatial coherence of the ship-induced "slope-enhanced" contribution to deep
ocean noise.

# TABLE OF CONTENTS

# THE  PRESENTATION

——— Sources Track with Measured Bathymetry
——— Measured Bathymetry Track
- - - - SYNBAPS Bathymetry Track

## INTRODUCTION

This paper presents the results of an experiment to investigate the coupling of sound from a shallow coastal source to a deep ocean receiver. The source and receiver were calibrated and the results were (1) transmission loss data which showed moderate slope enhancement of 4 dB and agreement with range averaged calculations; (2) the standard deviation of the received signal determined over a temporal and spatial ensemble was 1.7 dB for signal-to-noise ratios between six and twenty decibels; (3) the received signals for deep water transmission were found to have coherence lengths of greater than or equal to 460 m.

## THE EXPERIMENT - VIEWGRAPH #1

This experiment was conducted during August 1979 in the Northwest Atlantic Basin shown in viewgraph #1. A seismic array was towed between 1 and 2 knots at a depth of 750 m while a projector ship proceeded along a radial from the Sohm Abyssal Plain and up the Scotian Shelf to the Sable Island Bank. The tow tracks on the Scotian Shelf were up and down radials with an up and down traverse between the radial runs. The calibrated sound source was driven at a frequency of 135 Hz and a level of 188 dB re $1\mu$Pa at 1 m. The receiver consisted of calibrated hydrophone groups with a sensitivity of -186 dB re 1 Volt/$\mu$Pa.
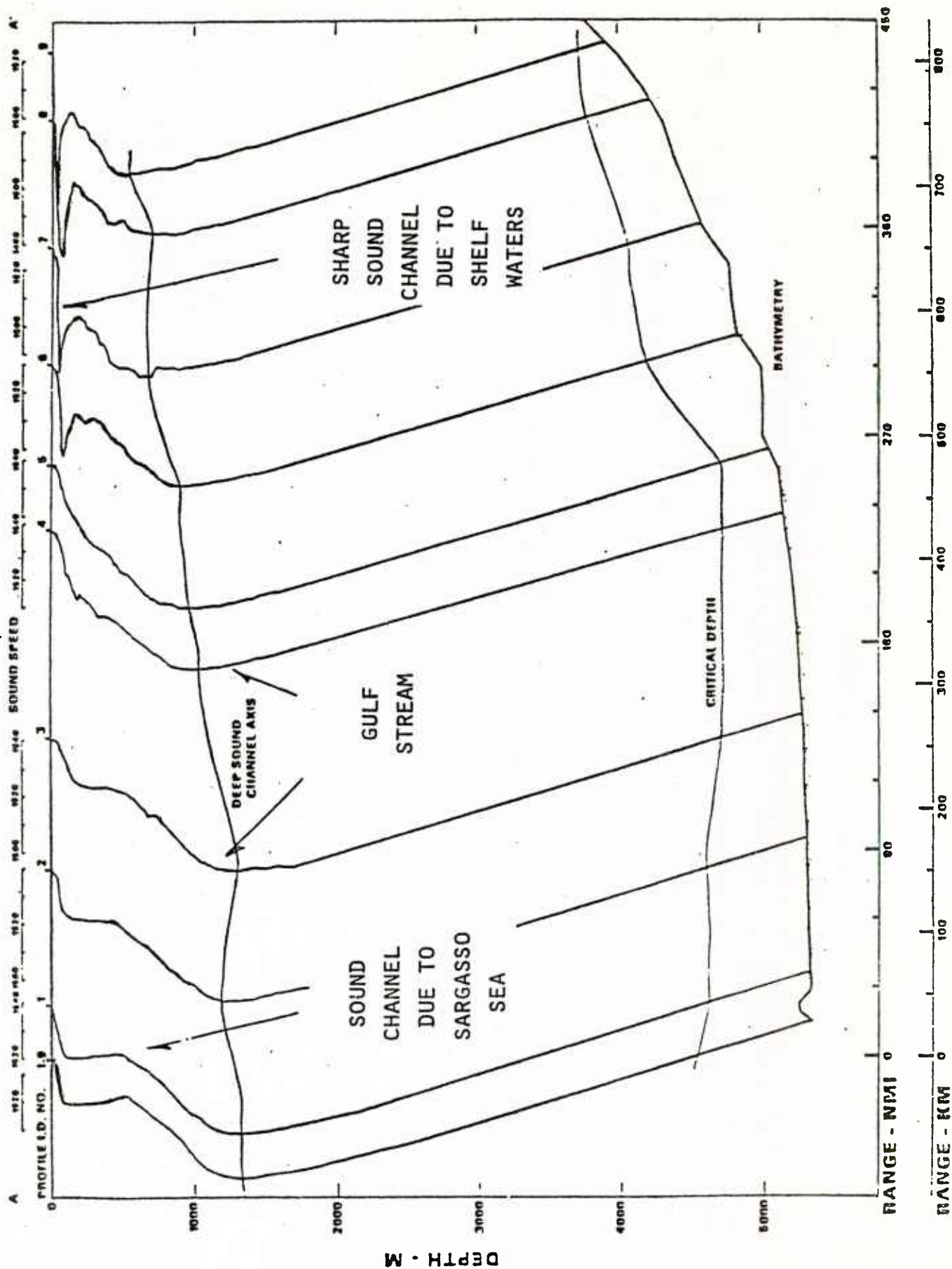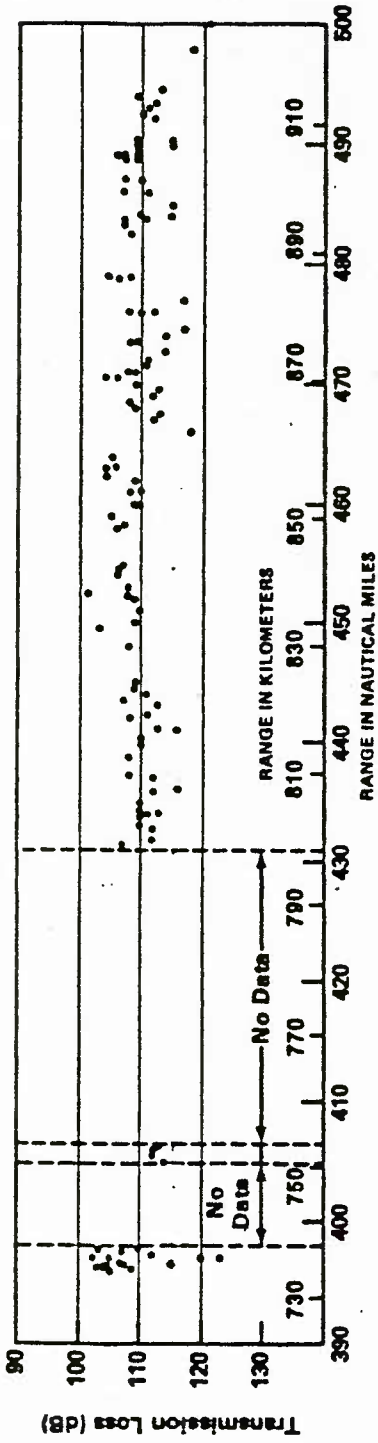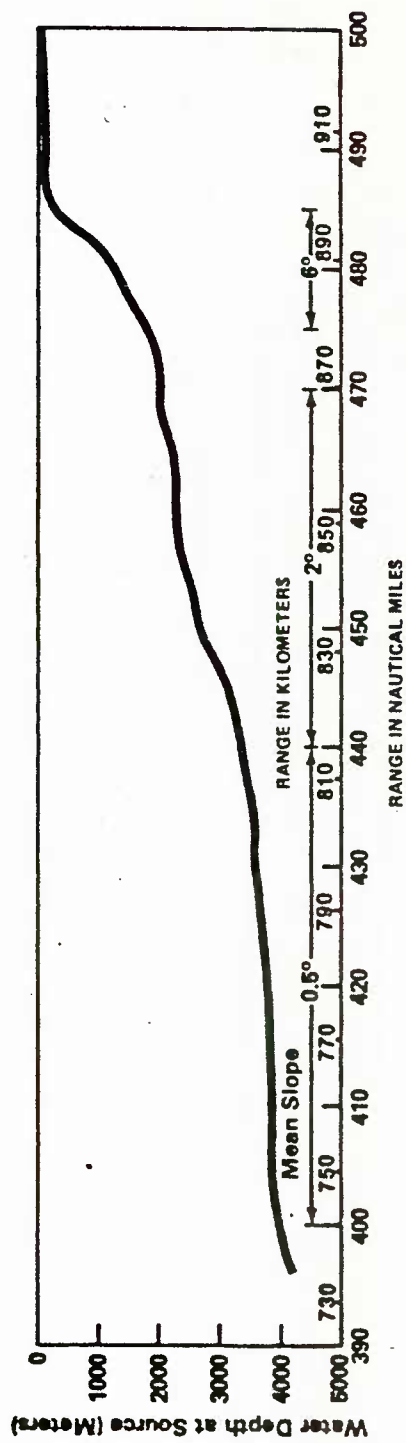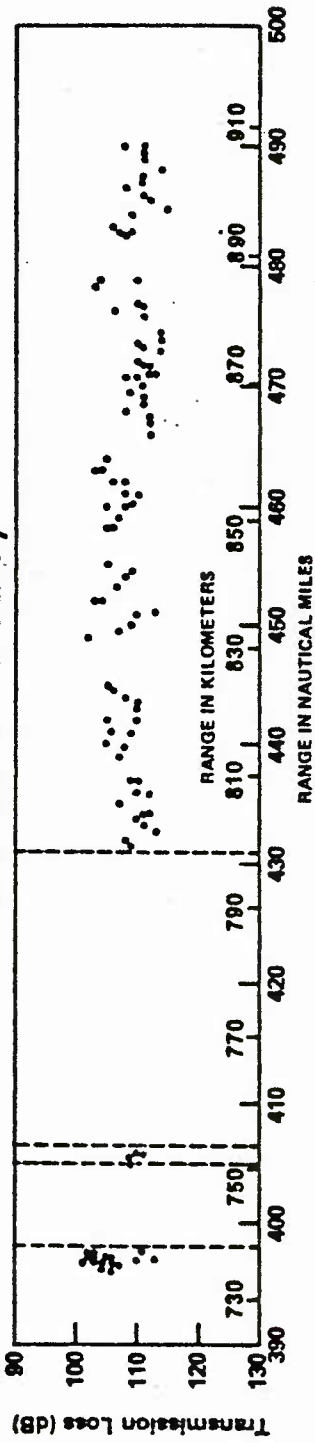
MEASURED SOUND VELOCITY STRUCTURE.

MEASURED SOUND VELOCITY STRUCTURE - VIEWGRAPH #2

The sound transmission path during this experiment was in a complex oceano-
graphic environment. The range dependent sound velocity structure was
determined by the merging of near surface bathythermograph measurements with
deep historical profiles from the NORDA Data Bank. Also shown is the measured
bathymetry. The actual track was longer than shown in this viewgraph. The
sound transmission from the 18 m source was from the region which was observed
to have a sharp sound channel due to the cold shelf waters, through the Gulf
Stream and into a region dominated by the Sargasso Sea.

## Single Hydrophone Data

Transmission Loss (dB)

90 100 110 120 130

390 730 400 750 410 770 420 790 430 440 810 450 830 460 850 470 870 480 890 490 910 500

RANGE IN KILOMETERS

RANGE IN NAUTICAL MILES

No Data

No Data

## 2nd Quarter of Array

Transmission Loss (dB)

90 100 110 120 130

390 730 400 750 410 770 420 790 430 440 810 450 830 460 850 470 870 480 890 490 910 500

RANGE IN KILOMETERS

RANGE IN NAUTICAL MILES

Water Depth at Source (Meters)

0 1000 2000 3000 4000 5000

390 730 400 750 410 770 420 790 430 440 810 450 830 460 850 470 870 480 890 490 910 500

RANGE IN KILOMETERS

RANGE IN NAUTICAL MILES

Mean Slope

0.5° 2° 6°

Transmission loss versus range at 135 Hz.

6

## TRANSMISSION LOSS VERSUS RANGE AT 135 Hz - VIEWGRAPH #3

Transmission loss results were derived from estimates of received signal power measured with calibrated omnidirectional hydrophone groups and from the relative range between the source and receiver determined from precision satellite navigation data. Projector levels were calibrated before the exercise and were monitored during the measurements. Data from the omnidirectional hydrophone groups were processed by an inphase-quadrature and digital filter technique (Madan, 1979 IEEE), (Rennie, 1979 IEEE) in three 5 Hz passbands centered on specific center frequencies. These data were then processed with a digital Fast Fourier Transform (FFT) with a Hann, time window weighting to yield power spectra with a frequency resolution of .08124 Hz. Center frequencies were chosen to avoid the scalloping loss due to misalignment of the frequency bin with the received doppler shifted signal. Noise estimates were made by utilizing four frequency bins shifted up and down from the signal frequency. Linear averages based on six, 12.5 second samples spread over 318 seconds were employed to make spectral estimates of signal level received at the omnidirectional hydrophone group represent temporal as well as spatial averages of the sound field. Data with signal-to-noise ratios greater than or equal to 6 dB were used to determine transmission loss values. The range estimates were determined for each data sample with the known position of the receiver and source vessels. Since both the vessels were in motion, these relative range values are plotted from the mean reference position of the receiver. Transmission loss results at 135 Hz for the first leg of the tow are shown which portray omnidirectional hydrophone group levels, an average of 16 hydrophone groups, and the measured bottom depth below the sound source. These results lack significant features, the data simply represent transmission loss values between 100 and 115 dB in a complex range dependent environment.
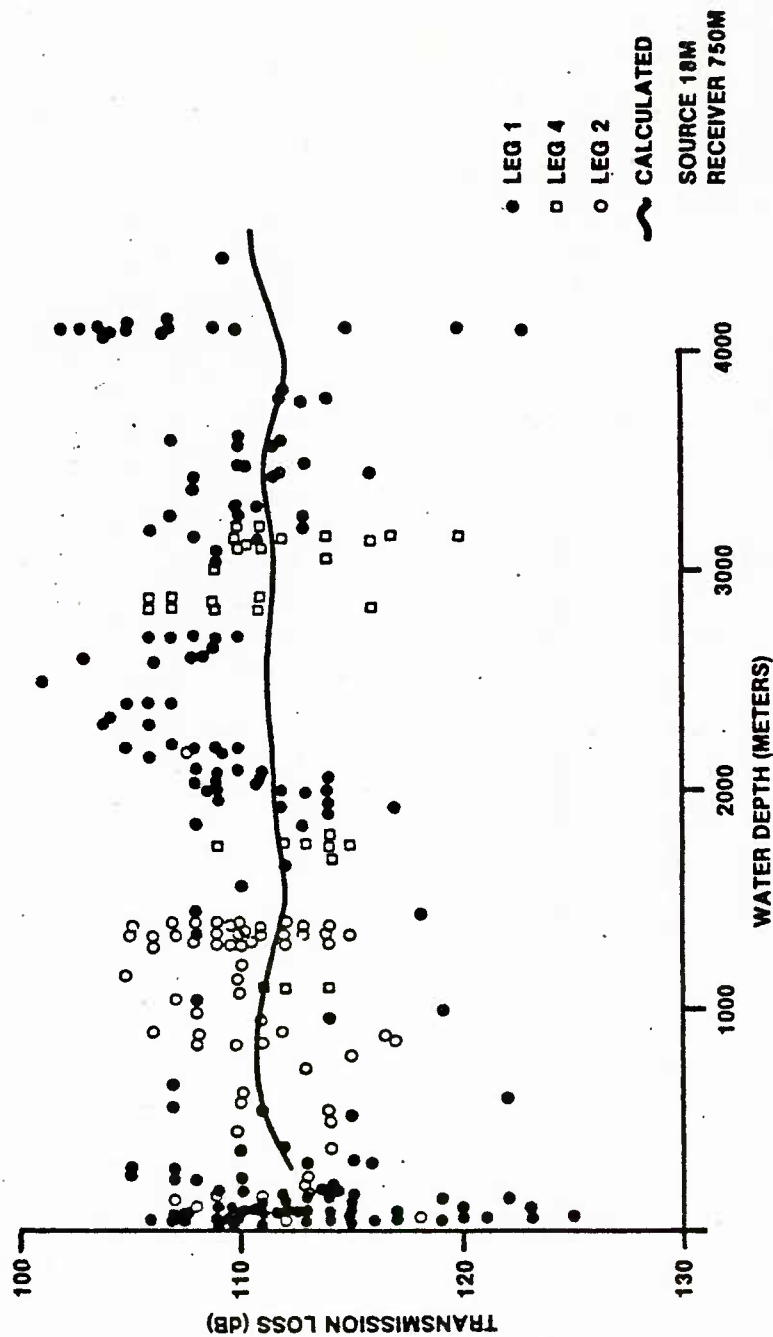
Transmission loss at 135 Hz versus water depths for source
receiver ranges between 395 and 500 nmi. Data was not
corrected for cylindrical spreading (∿1.2 dB). Also
shown are parabolic equation, range averaged (20 Km),
calculated values.

TRANSMISSION LOSS AT 135 Hz VERSUS WATER DEPTH - VIEWGRAPH #4

The data from other portions of the slope are shown in this viewgraph as a
function of water depth beneath the 18 m sound source. When the water depth was
100 m or less pronounced increases in transmission loss values were observed.
Also shown on this viewgraph is the calculated transmission loss for a "flat"
bottom. At the same water depths data from each leg appears to have comparable
transmission loss values and thus these data form a representative sample of the
transmission loss over this area of the Scotian Shelf. The slope enhancement is
taken as the difference between the flat bottom P.E. calculation and the measured
data. Slope enhancements are found as high as 10 dB but the median slope en-
hancement was found to be 4 dB. This represents the competition between the
bottom reflected, higher angle energy and loss of the lower angle energy in the
sharp near surface sound channel.
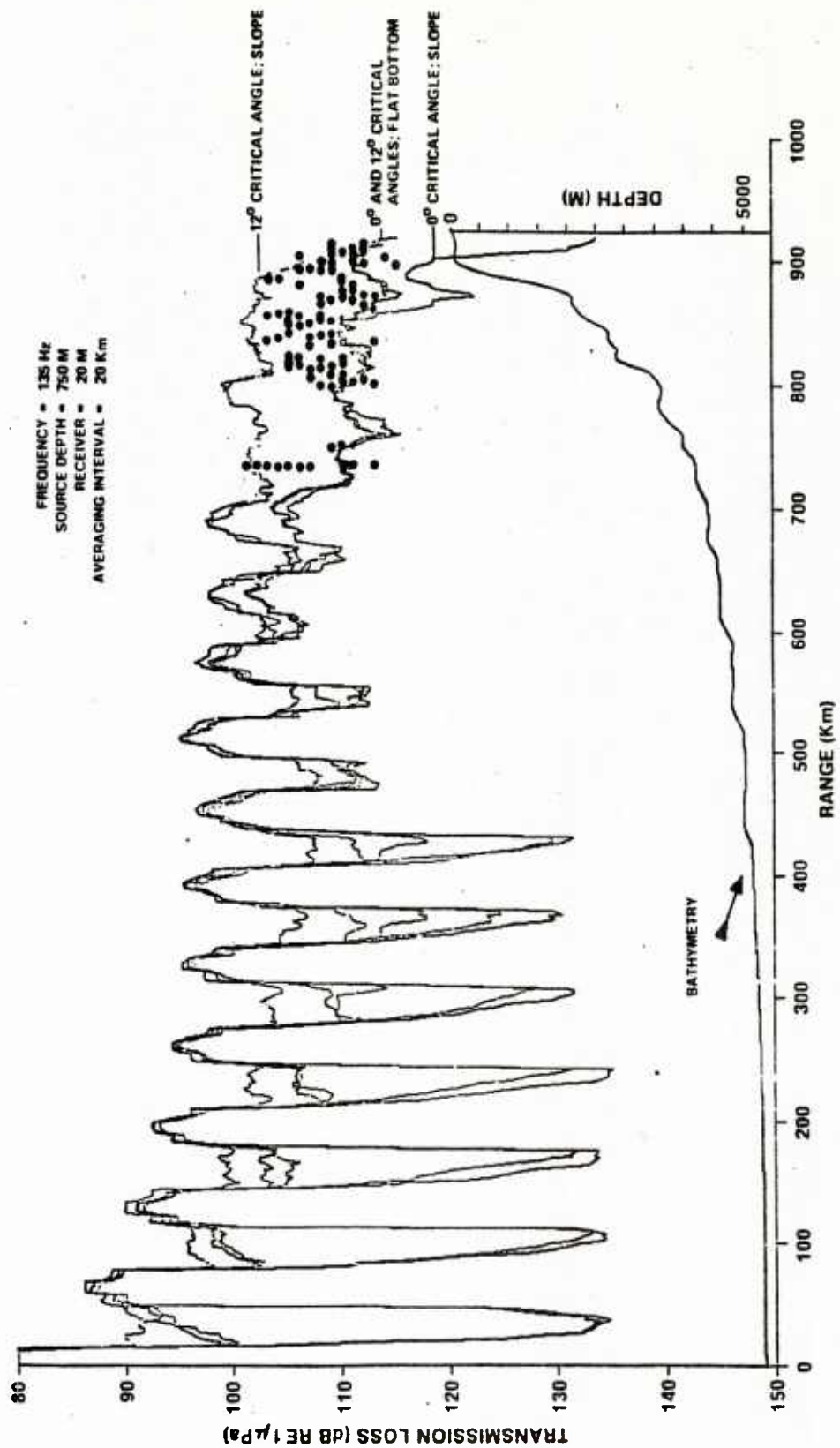
Calculated versus measured transmission loss results.

The transmission loss data obtained in this experiment were interpreted in a quantitative manner by comparison with numerical computations from both NORDA and NRL P.E. codes as well as by ray tracing.  Bottom loss measurements from NADC and geologic data from the Deep Sea Drilling Project indicated that for this region of the Scotian Shelf that the loss characteristic was 0 dB to an angle of $30^{\circ}$ and to increase smoothly to 6 dB per bounce for angles greater than $40^{\circ}$ at a frequency of 100 Hz.  Nevertheless qualitative agreement was obtained between the range averaged parabolic (small angle approximation) equation results and experimental data (Viewgraph 5A).  The key to obtaining agreement between numerical computations and experimental data was the knowledge of the range dependent environment and the correct interpolation between measured profiles.
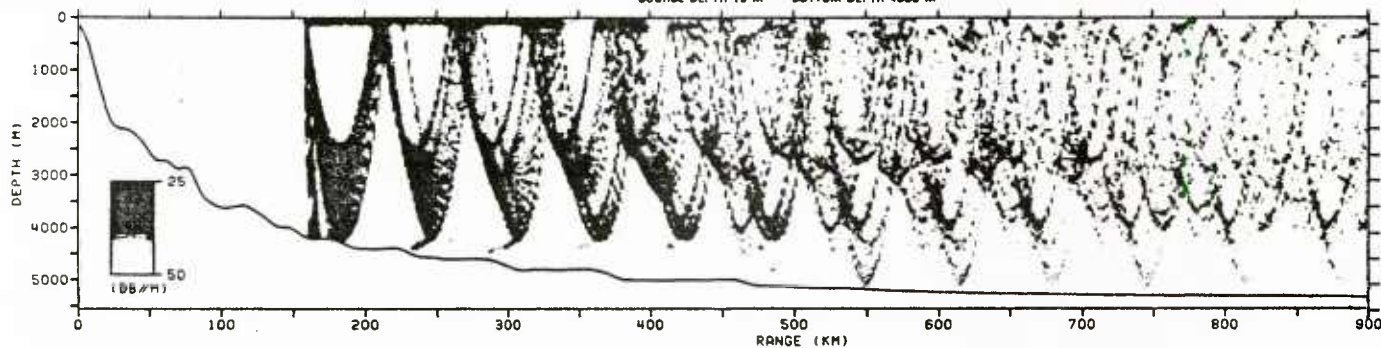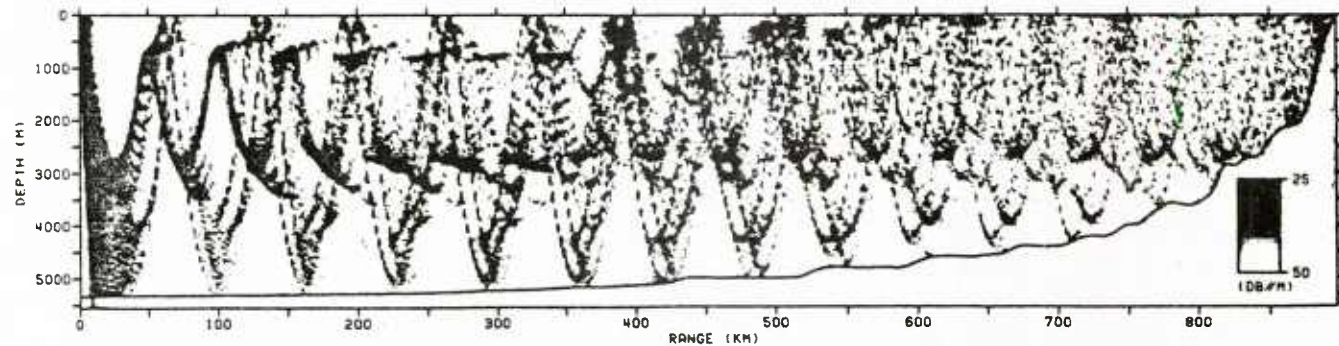
SOURCE DEPTH 18 M — BOTTOM DEPTH 100 M
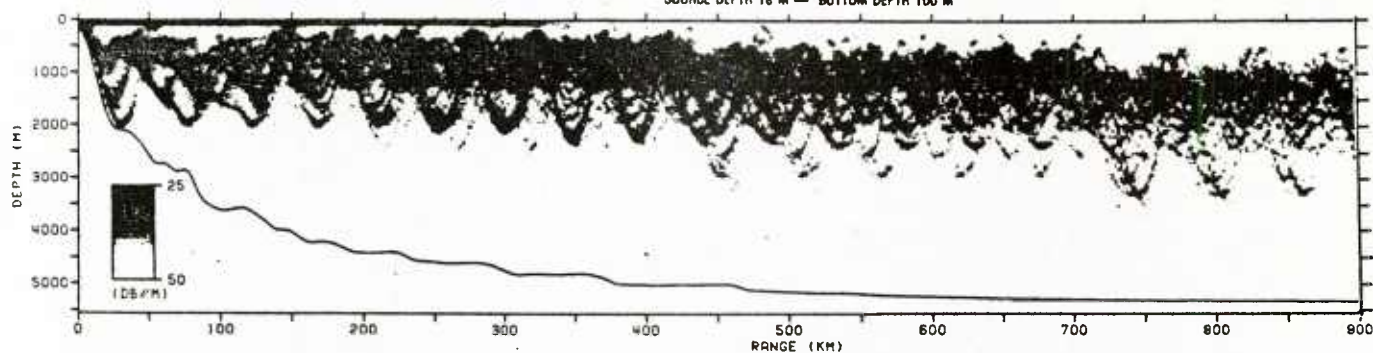
SOURCE DEPTH 18 M — BOTTOM DEPTH 806 M
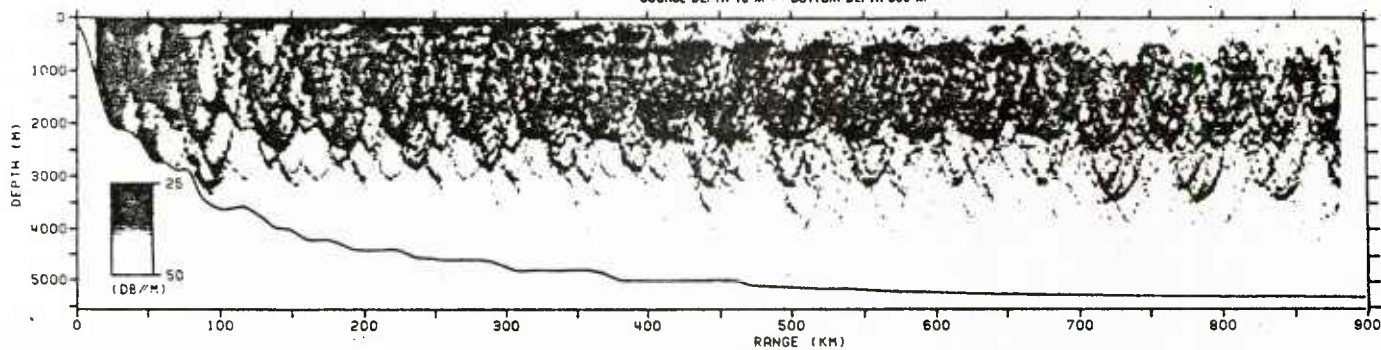
SOURCE DEPTH 18 M — BOTTOM DEPTH 4000 M

SOURCE DEPTH 750 M — BOTTOM DEPTH 5300 M

12

## INTENSITY SHADE PLOTS - VIEWGRAPH #5B

The intensity shade plots shown in this viewgraph (5B) are shown to demonstrate
the coupling of the sound reflected from the slope to the deep sound channel.
For ease of computation a coarser interpolation was used in the production of
these shade plots. However one can observe that the receiver at 750 m was in a
region dominated by up and down coming rays. These shade plots show trapping of
acoustic energy in the near surface sound channel. The top three are for
different source position on the shelf while the bottom is the reciprocal field
picture.

SIGNAL + NOISE → SENSOR → $f_c, \Delta f$ → $Y = X^2$ → $\int_0^{T_{avg}} Y\,dt$ → $\sum_{i=1}^{M} <Y_i>$ →
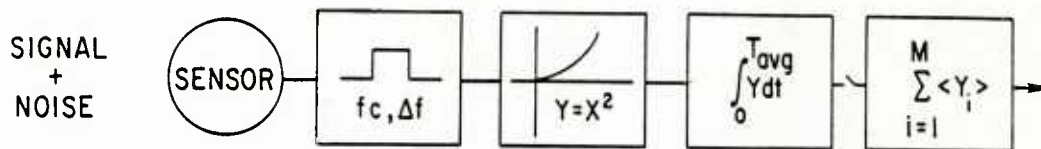
1. DYER : RANDOM SIGNAL $\quad P(r_i, t) = C \sum_{n=1}^{N} A_n \cos(\omega t + \omega \tau_n + \theta_n)$

2. $<P_i^2(r)> = P_0^2 \tau_0^2 \left[ \left[ \dfrac{1}{N} \sum_{n=1}^{N} A_n \cos\phi_n \right]^2 + \left[ \dfrac{1}{N} \sum_{n=1}^{N} A_n \sin\phi_n \right]^2 \right]$

FOR $0 \leq t \leq T_{avg}$ ; $\dfrac{2\pi}{\omega} \leq T_{avg} \leq T_{dynamic}$ .

3. THE PROBABILITY DISTRIBUTION

$$P\left(<\dfrac{P^2}{P_0^2}>\right) = \dfrac{1}{2\sigma^2} \exp\left(-<P^2>/P_0^2/2\sigma^2\right) ; \quad 0 \leq <P^2/P_0^2> \leq \tau_0^2$$

THIS IS A 2dF $X^2$ DISTRIBUTION OR EXPONENTIAL.

4. THE LOG TRANSFORMATION YIELDS $\quad P\left(\ln\left(\dfrac{<P^2>}{P_0^2}\right) = Y\right) = \dfrac{1}{2\sigma^2} \exp\left(Y - e^{-Y}/2\sigma^2\right)$

$$-\infty < Y \leq \ln\tau_0$$

THE MEAN $\quad \mu_y = \ln 2\sigma_1^2 - \gamma = \ln\tau^2 - \gamma$

$\quad\quad\quad\quad \sigma_y = \dfrac{\pi^2}{6}$

5. IN GENERAL FOR SIGNAL + NOISE, WE HAVE WITH M POST AVERAGING SUMS:

$$P(<P^2>) = \dfrac{1}{2} \left(\dfrac{<P^2>\sigma^2}{MA^2}\right)^{(M-1)/2} \exp\left(\dfrac{-MA^2}{\sigma^2} - \dfrac{<P^2>}{2}\right) I_{m-1}\left(\dfrac{<P^2>MA^2}{\sigma^2}\right)$$

14

## THE SQUARE LAW MEASUREMENT SYSTEM - VIEWGRAPH #6

The analog to the measurement scheme used in this experiment is shown in view-graph #6. The basic signal conditioning is simply a narrowband filter, a square law device, an integrator and post detection summation. In general for the case of a deterministic signal in a Gaussian noise background we find (Whalen) that the statistics of the output are described by a non-central $\chi$ square distribution, shown at the bottom of the viewgraph, with a non-central parameter described by the signal-to-noise ratio ($A^2/\sigma^2$). When this ratio is large such as in this experiment we have primarily a distribution which depends on the signal properties and this expression essentially reduces to Dyer's treatment of sound propagation. As shown in (1) the signal can be represented as having random properties; $A_n$ represents the amplitude of the nth path, $\omega\tau_n$ represents the travel time of the nth path, and $\theta_n$ represents phase randomness due to the scattering along the nth path. Dyer shows (2) that for the short time average (Tavg) where Tavg is greater than the periodicity but less than the dynamics of the medium, that the short time average represents the sum of the squares of two random variables. When the term $\phi_n$ is random and n>3, by the central limit theorem these sums become Gaussian and the sum of the squares becomes the 2-dF Chi square ($\chi^2$) or exponential distribution. This is a special case of the non-central $\chi^2$. A log transformation yields the log normal distribution and the saturation variance of $\pi^2/6$. The major point to be made is when the number of paths are >3 and the phase either due to $\omega\tau_n$ or $\theta_n$ has a random component then our statistic has a standard deviation of 5.6 dB. An observed standard deviation less than 5.6 dB implies that the number of paths are small and the randomness in phase is not dominant. The envelope statistics fall under the same formulism and are discussed by Urick.
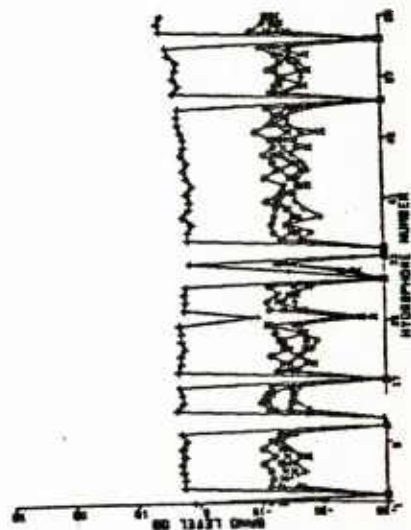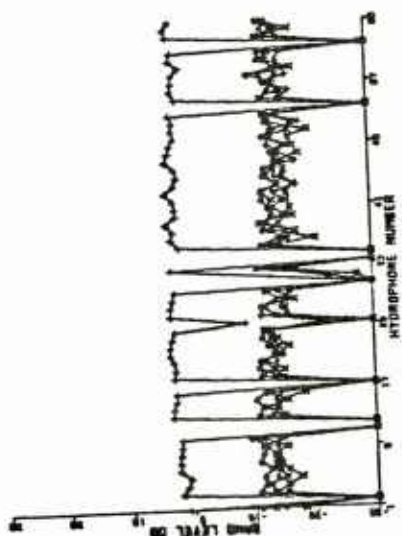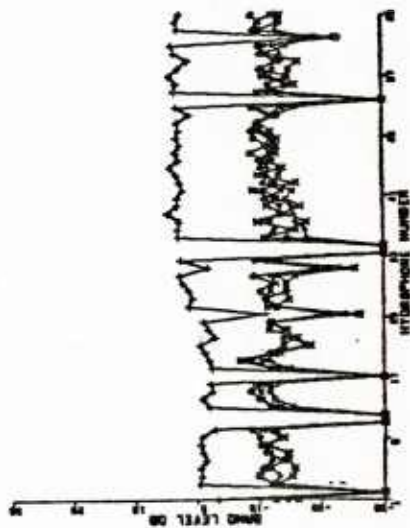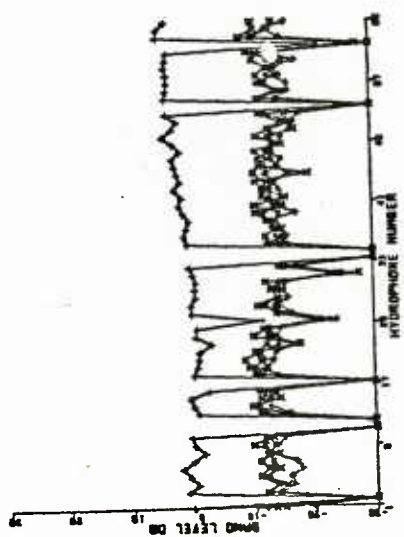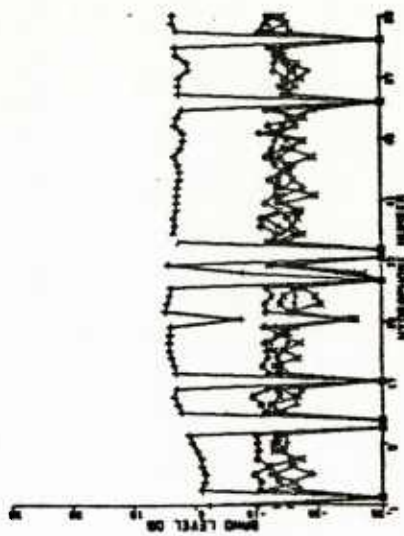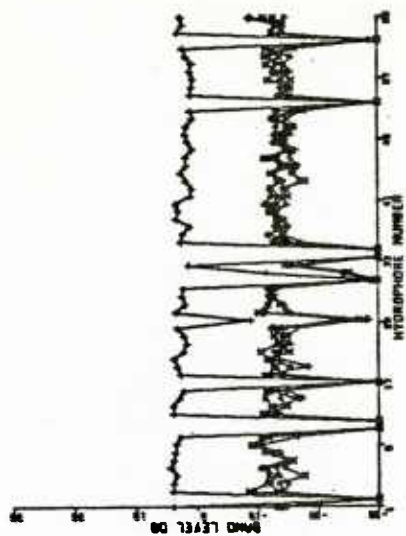
This viewgraph shows data obtained along the seismic streamer at six different periods of time. The plots show relative band level versus hydrophone number for both signal and noise bins. These data represent an average over a six minute period. The rapid dips in the curves are due to dead hydrophone groups. The curves show that indeed our streamer was nearly horizontal (little scalloping) and the flatness or gentle undulations suggest that no rapid fluctuations in the field are being observed. These data span a time period of some 22 hours.
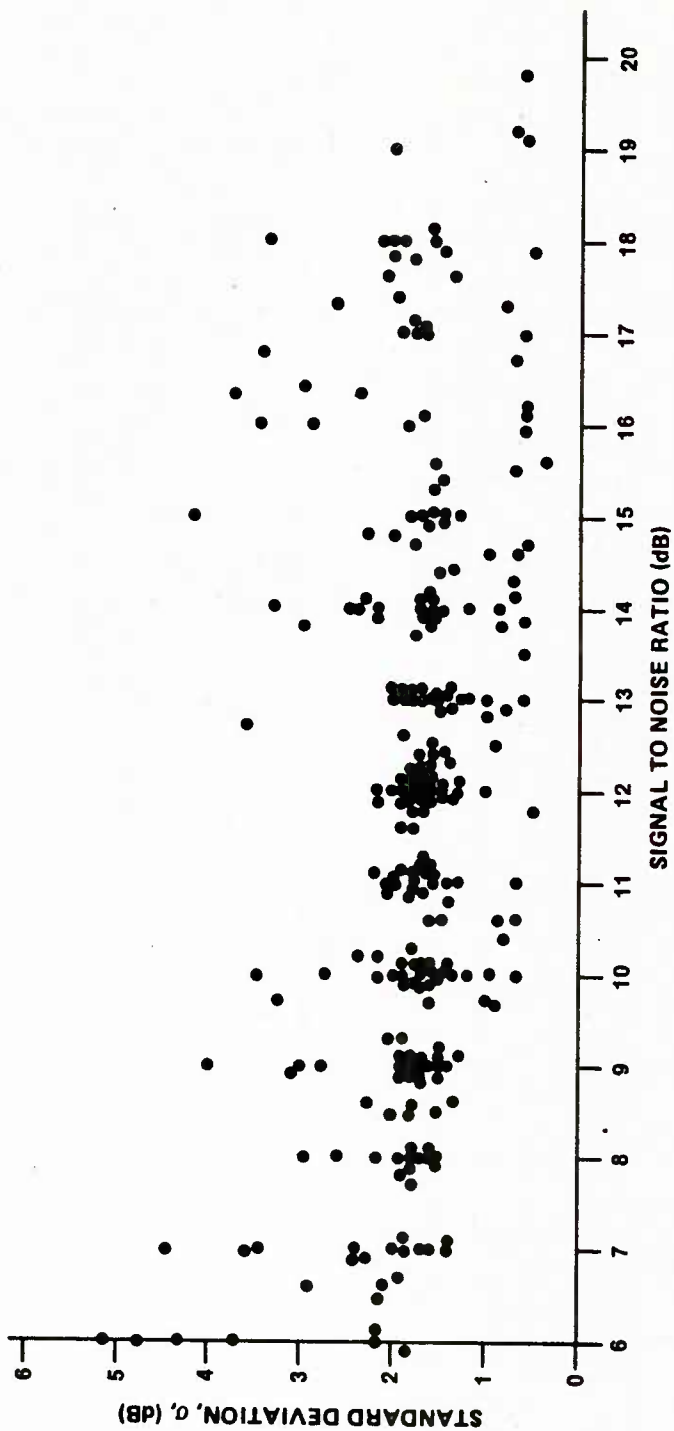
Standard deviation versus signal to noise ratio for received signal level for the 135 Hz tone. (Spatial average over 75 Meters, motion average over 800 Meters).

STANDARD DEVIATION VERSUS SIGNAL-TO-NOISE RATIO - VIEWGRAPH #8

The variance in time and space was computed for the 135 Hz signal. This variance was taken to be proportional to the sum of the squares of the differences between the mean intensity of six time samples and sixteen spatial samples, and the instantaneous intensity estimates. The value of the standard deviation was determined from the normalized square root of the variance. The results are shown in viewgraph #8 wherein the standard deviations are clustered about 1.7 dB. In several instances the standard deviations are greater than 4 dB as suggested by Dyer but for most of the cases with signal-to-noise ratios between 6 dB and 20 dB, they are less than 2 dB. The reason for these low standard deviations is related to the spatial variation of the receiver in the deep sound channel multipath field. These results indicate that sound transmission from a 135 Hz source at an 18 m depth over the Scotian Shelf couples strongly to RR propagation in the deep sound channel. The low values of the standard deviations observed in this experiment are an indication that only a few paths were dominant in the deep sound channel.
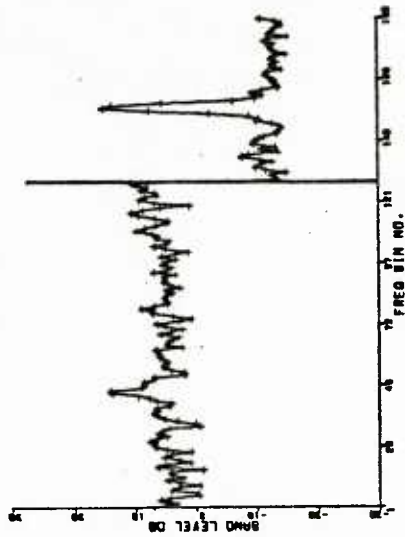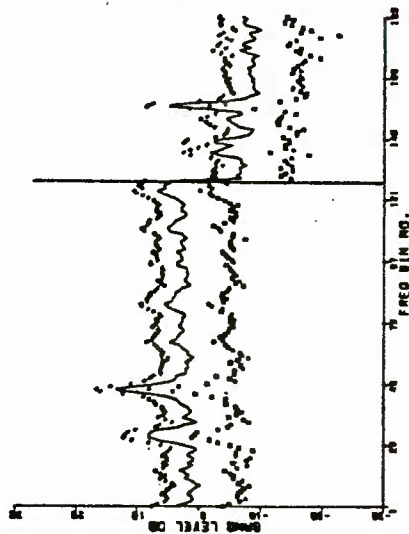
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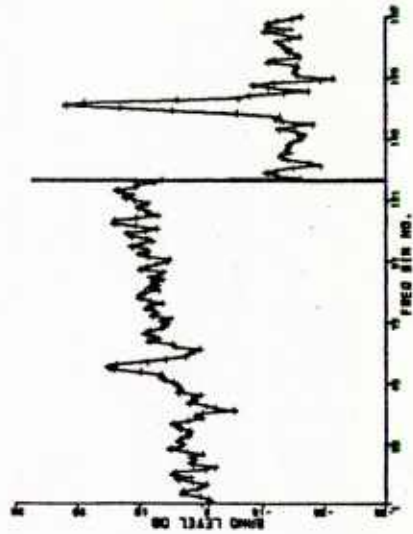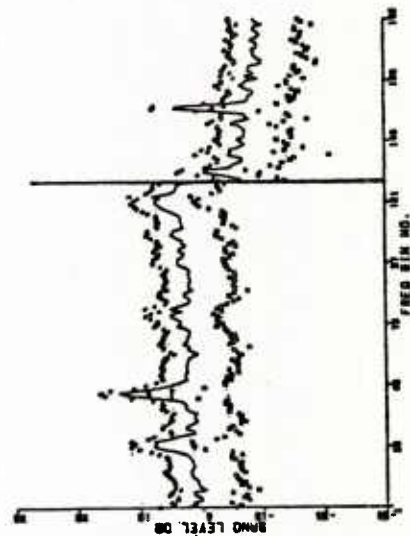
## REPRESENTATIVE SPECTRA - VIEWGRAPH #9

This viewgraph shows the relative spectra for the average hydrophone and the coherent summation of the hydrophones. These figures show 3 (4 Hz) filters centered at 36.2, 55 and 135 Hz. The last filter contains the 64 (.08 Hz) bins centered on 135 Hz. The figure on the left shows the intensity determined standard deviation on the average hydrophone signal and noise. On the right hand side of the viewgraph one observes the coherent summation of hydrophones when the distant source is near broadside. The ratio of these two spectral peaks is taken as the estimate of coherent gain.
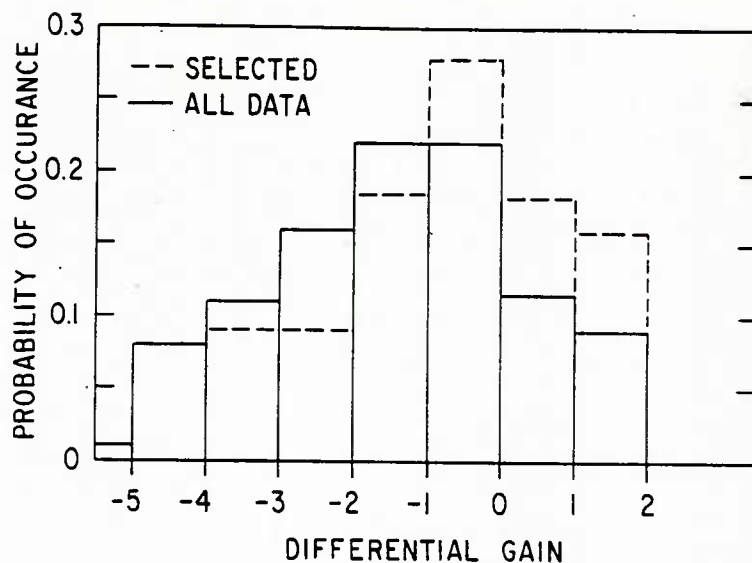
THE ESTIMATION OF COHERENCE AND COHERENCE LENGTH

SIGNAL COHERENCE $\quad \rho_{sij} = e^{-(d_{ij}/Lc)^n}$

ARRAY SIGNAL GAIN $\quad$ ASG $= 10 \, LOG \left[ \sum_i \sum_j \rho_{sij} \right]$

DIFFERENTIAL GAIN $\quad$ DG $= -10 \, LOG \left[ \sum_i \sum_j \rho_{sij} \, / \, N^2 \right]$

$$= -10 \, LOG \left[ \sum_i \sum_j e^{-(d_{ij}/Lc)^n} \, / \, N^2 \right]$$

SELECTED BROADSIDE DATA $\quad$ DG $= -0.5 \, dB \quad \sigma = \pm 1.5 \, dB$

ALL DATA $\quad$ DG $= -1.2 \, dB \quad \sigma = \pm 1.7 \, dB$

BASED ON SELECTED DATA $\quad$ $n = 1.5 \quad Lc \sim 460 \, m \quad (150 \, m)$

$\qquad\qquad\qquad\qquad\qquad\quad$ $n = 2.0 \quad Lc \sim 352 \, m \quad (150 \, m)$

## THE PROBABILITY DENSITY OF DIFFERENTIAL GAIN - VIEWGRAPH #10

The histogram of differential gain is shown in viewgraph #10 for data with hydro-
phone signal-to-noise ratios greater than 6 dB.  I refer to differential gain as
the negative difference between 20 Log(N) and the measured gain.  This figure
contains two curves.  The first represents selected "deep water" cases while the
second represents a larger sample containing the effects of bottom, scalloping,
and beam splitting.  The deep water values were found to have a -0.5 dB differ-
ential gain with a standard deviation of 1.5 dB.  These data when interpreted by
a coherence formulation of the form $\exp(-d_{ij}/L_c)^n$ yield  coherence lengths of
460 m and 352 m whether one employs $n = 1.5$ as do Beran and McCoy or $n = 2.0$ as
per Flatte.  The variation on the gain measurements is real and must be con-
sidered in performing this kind of experiment.  This approach to the estimation
of coherence provides for a larger number of degrees of freedom than the pairwise
coherence measurements as discussed by G. Carter (IEEE, 1979).

## CONCLUDING REMARKS

This paper has presented data from a sound transmission experiment with a shallow
source (18 m) to a deep ocean (750 m) receiver. The results show that bottom re-
flected energy from the slope coupled to RR propagation in the deep sound channel.
This resulted in a well behaved field of "up and downing" coming arrivals and con-
sequently a temporal and spatial standard deviation of 1.7 dB. In addition the
data appeared to be coherent and estimates of the coherence based on coherent
summation of broadside arrivals yield lengths on the average greater than 460 m or
352 m whether a Beran or Flatte model was employed.

## SUMMARY

The experimental results presented in this paper fall in the class of acoustic
propagation problems describing slope interaction coupling to the deep sound
channel with sufficient depth excess to support RR propagation. Transmission loss
results at 135 Hz for a shallow (18 m) source over the Scotian Shelf at ranges
between 395 and 500 nmi were presented based on calibrated source levels and
received signals on omnidirectional hydrophone groups with signal-to-noise ratios
greater than 6 dB (and as high as 20 dB). The standard deviations of these re-
ceived signal estimates over a horizontal distance of 75 meters and a displacement
due to source and receiver motion of 800 meters had a mean value of 1.7 dB with no
strong dependence on the signal-to-noise ratio. The transmission loss values over
the shelf spanned by up and down slope runs, had slope enhancements of between
0 dB and 10 dB with a median value of 4 dB determined from a range-averaged, flat
bottom, parabolic equation calculation.

The description of the transmission of sound in this experiment required the
treatment of a range dependent sound field. The deep water portion of this field
was dominated by the double sound channel, the mid portion a smooth sound channel,
and the shelf portion a sharp shallow sound channel. The parabolic equation
approximation was used to calculate the range dependent sound field for critical
angles of $0^{\circ}$, $12^{\circ}$ and $30^{\circ}$ for both the flat and sloping bottom. It should be

recognized that this method is basically a small angle approximation and cannot adequately handle the larger angles ($12^\circ$ to $30^\circ$). Furthermore, the calculations were performed with the receiver in shallow water and the source in deep water. The calculated values of the transmission loss bracketed the data.

To obtain a qualitative interpretation, an ARAD was used to show that energy leaving the source with angles between $\pm 19^\circ$ experienced one bottom bounce before becoming coupled to the deep sound channel and that energy between $19^\circ$ and $24^\circ$ experienced two bottom bounces. Measured bottom loss in this region was low (0.5 dB) over an angular range of $25^\circ$. The sharp, near-surface shallow channel resulted in ducted propagation and a reduction in the slope enhancement effect. The acoustic energy directed at higher angles, due to the dipole field, resulted in an increased slope interaction and an increase in the energy coupled into the deep sound channel. The net results of these two countering effects was a median slope enhancement of 4 dB. These considerations stress the importance of high, ray-angle energy in the slope enhancement problem, and consequently the require-ment for a computational technique capable of treating this conversion of high ray-angle energy into small ray-angle RR propagation. In addition, these results suggest that for water depths greater than 100 m, low bottom loss at small grazing angles, and for those cases where the number of bounces are few, the computation may be feasible. The importance of the water mass and its variability over the slope cannot be understated. In this experiment, the presence of the slope water and its production of a shallow sound channel had the effect of suppressing the slope enhancement.

Because coastal water masses vary with season of the year and prevailing wind directions, this shelf water could produce a seasonal variation in the deep basin ambient noise spectrum as a consequence of the seasonal variation in the near surface sound channel. In addition, coastal shipping will produce a depth dependent noise field related to the density of a coastal shipping, the slope of the shelf, and the properties of the slope and shelf waters.

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# REFERENCES

Beran, M., McCoy, J., Adams, B., "Effects of a Fluctuation Temperature Field on the Spatial Coherence of Acoustic Signals," NRL, Rept. 17809 (1975).

Beran, M.J., and McCoy, J.J., "Directional Spectral Spreading in Randomly Inhomogeneous Media," J. Acoust. Soc. Amer. 66, 1468-1471 (1979).

Carter, G.C., "Confidence Bounds for Magnitude Squared Coherence Estimates," NOSC T.D.#5881, 13 July 1978, NUSC, New London, CT.

Dyer, I., "Statistics of Sound Propagation in the Ocean," J. Acoustic Soc. Am. 48(1), 337-345, (1970).

Feuillet, Jean-Pierre, Carey, W.M., "Measurement of the Acoustic Lloyd Mirror Interference Pattern at the Mid-frequency," 103 ASA Spring Meeting - 71(S1), S84(A).

Flatte, S.M., Dashen, R., Munk, W., Zachariosen, "Limits on Coherent Processing due to Internal Waves," Stanford Research Institute, TR JSR 76-14, June 1977.

Madan, R., "Fir Digital Filters in a Linear Array Processor," Proc. of IEEE Oceans '79, CONF pp 1-5, September 1979.

Rennie, L.J., "The TAP III Beamforming System," Oceans '79 (79CH 1478-70EC), Paper (CH1478-7179/0000), pp 6-13, (1979), IEEE, 345 East 47th St, New York.

Urick, R.J., "Models for the Amplitude Fluctuations of Narrowband Signals and Noise in the Sea," J. Acoust. Soc. Am. 62(4), 878-887 (1977)

Whalen, A., Detection of Signals in Noise, Academic Press, (1971), New York.